CONF-810312--1

LA-UR-80-3528

TITLE: AMPLIFIED REFLECTION VIA DEGENERATE FOUR-WAVE MIXING IN A LASER INDUCED FREE CARRIER PLASMA IN GERMANIUM

MASTER

AUTHOR(S): D. E. Watkins, L-9
C. R. Phipps, Jr., L-9
S. J. Thomas, L-9

SUBMITTED TO: International Conference on Excited States and Multiresonance Nonlinear Optical Processes in Solids, Centre Paul Langevin, CAES du CNRS Aussois, 73500 Modane, France
March 18 - 20, 1981

DISCLAIMER

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

Form No. 836 R3
St. No. 2629
12/78

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

AMPLIFIED REFLECTION VIA DEGENERATE FOUR-WAVE MIXING IN A LASER INDUCED FREE CARRIER PLASMA IN GERMANIUM*

D. E. Watkins,** C. R. Phipps, Jr. and S. J. Thomas
University of California
Los Alamos Scientific Laboratory
Los Alamos, NM 87545

Abstract

We present the first observation of amplified reflection at CO_2 laser wavelengths via degenerate four-wave mixing in an optically induced free-carrier plasma in germanium. Reflectivities of over 100% are reported in both n-type and p-type Ge. A model is presented which predicts both the magnitude and the I^{11} intensity dependence of the reflectivity from the free carrier plasma density. This density is determined experimentally by time-resolving the incident and transmitted signals obtained above the plasma formation threshold and deducing the free carrier density via a detailed model which relates this quantity to the instantaneous, intensity-dependent transmission.

---

*Work performed under the auspices of the U. S. Department of Energy.

**Ph.D. Candidate, University of Washington, Seattle, WA.

AMPLIFIED REFLECTION VIA DEGENERATE FOUR-WAVE MIXING IN A LASER INDUCED FREE CARRIER PLASMA IN GERMANIUM*

D. E. Watkins,** C. R. Phipps, Jr. and S. J. Thomas
University of California
Los Alamos Scientific Laboratory
Los Alamos, NM 87545

We present the first observation of amplified reflection at 10.6 μm via degenerate four-wave mixing in an optically induced free carrier plasma in germanium.[1] Reflectivities of 100 - 800% have been observed in several samples of Ge pumped at intensities of about 100 MW/cm^2.

Figure 1 shows the results of wave mixing experiments in two samples of Ge, each 3 mm long, one optical grade and the other p-type with an acceptor concentration of 6 x 10^{15} cm^{-3}. The plasma formation occurs at intensities above about 80 MW/cm^2 in the counter-propagating pump geometry, and in this regime the reflectivity exhibits a dramatic increase. The reflectivity varies approximately as the eleventh power of intensity over the range $80 < I < 120$ MW/cm^2. Amplification of the forward beam was also observed and we measured an increase of about 80% in this signal, correlated to the large reflectivities.

We can estimate the reflectivity by calculating the change in index of refraction due to optically induced free-carrier density and using this in the formula for reflectivity given by Yariv and Pepper[2].

---

*Work performed under the auspices of the U. S. Department of Energy.

**Ph.D. Candidate, University of Washington, Seattle, WA.

The free-carrier density is determined experimentally by carefully time resolving the incident and transmitted signals obtained above the plasma formation threshold in Ge and deducing the free-carrier density via a detailed model we developed[3] which relates this quantity to the instantaneous, intensity-dependent transmission. In this procedure, a bivariate reverse iteration is performed, applying Rigrod theory with loss[4] to experimental time-resolved transmission data. The model for the total local absorption coefficient ignores only the Drude-Zener absorption of the heavy holes to obtain the appropriate fixed and bleachable components of the absorption. In this way, we determine what average excess carrier density would have provided the observed transmission with the appropriate spatial variation of the heavy to light hole partition. When this is done with three samples of intrinsic germanium of different lengths, results such as in Fig. 2 are obtained.

In the figure, the threshold for strong photoionization in a unidirectional beam is seen to be about 200 MW/cm^2. Above this intensity, excess carrier density varies with intensity to the 5.5 power.

The change in index of refraction due to free carrier generation is given by

$$\Delta n = -\frac{2\pi e^2 N}{n_o m_e \omega^2}\left\{\frac{1}{m_c^*} + \frac{[1+(1+I/I_s)^{-\frac{1}{2}}]}{2m_H^*} + \frac{[1-(1+I/I_s)^{-\frac{1}{2}}]}{2m_L^*}\right\}$$

where N is the intensity-dependent free-carrier density from Fig. 2, n_o is the linear index refraction, m_e is the mass and e the charge of an electron, $m_c^*/m_e = 0.12$, $m_H^*/m_e = 0.31$ and $m_L^* = 0.044$

are the effective masses for the conduction, heavy-hole, and light-hole bands respectively.

For $N = 2.5 \times 10^{15}$ cm^{-3} and $I/I_s = 125$, we obtain $\Delta n = -6.4 \times 10^{-4}$. From Yariv and Pepper, the reflectivity produced by this refractive index is given by $R = \tan^2 (k_0 \Delta n L)$ where k_0 is the free space wave number and L is the interaction length. For L = 3 mm, we obtain R = 4.8, in reasonable agreement with experiment. This model also predicts that the reflectivity varies as I^{11}, consistent with experimental results.

References

1. For similar work near resonance with the band gap see R. K. Jain et al., Appl. Phys. Lett. 4, 328 (1979) or M. A. Khan et al., Opt. Lett. 5, 261 (1980).
2. A. Yariv and D. M. Pepper, Opt. Lett. 1, 16 (1977).
3. D. E. Watkins et al., Opt. Lett., to be published, Feb. 1980.
4. W. W. Rigrod, J. Appl. Phys. 34, 3602 (1963).

Figure Captions

Fig. 1. - Reflectivity in 3 mm samples of p-type (*) and optical grade (+) Ge. The lines are models of reflectivity based on saturable absorption in p-type Ge and the nonlinear index in optical grade Ge.

Fig. 2. - Peak free carrier density versus peak input intensity in intrinsic germanium with three different sample lengths. o: 5.7 cm, Δ: 9.7 cm and *: 14.2 cm. The trend line represents $I^{5.5}$.

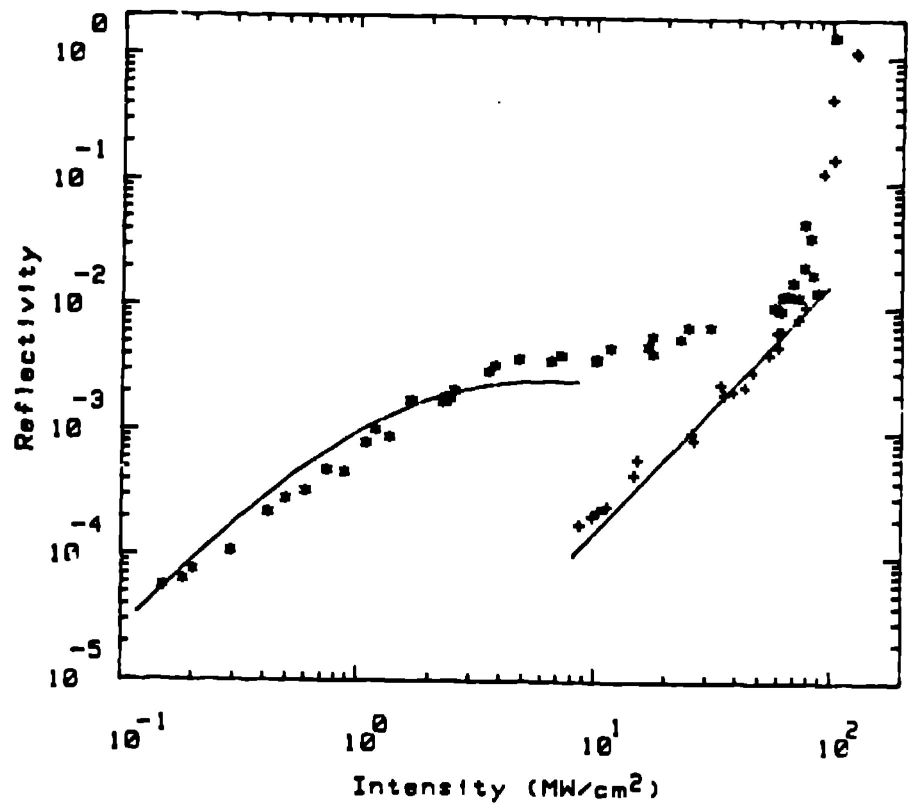

Figure 1

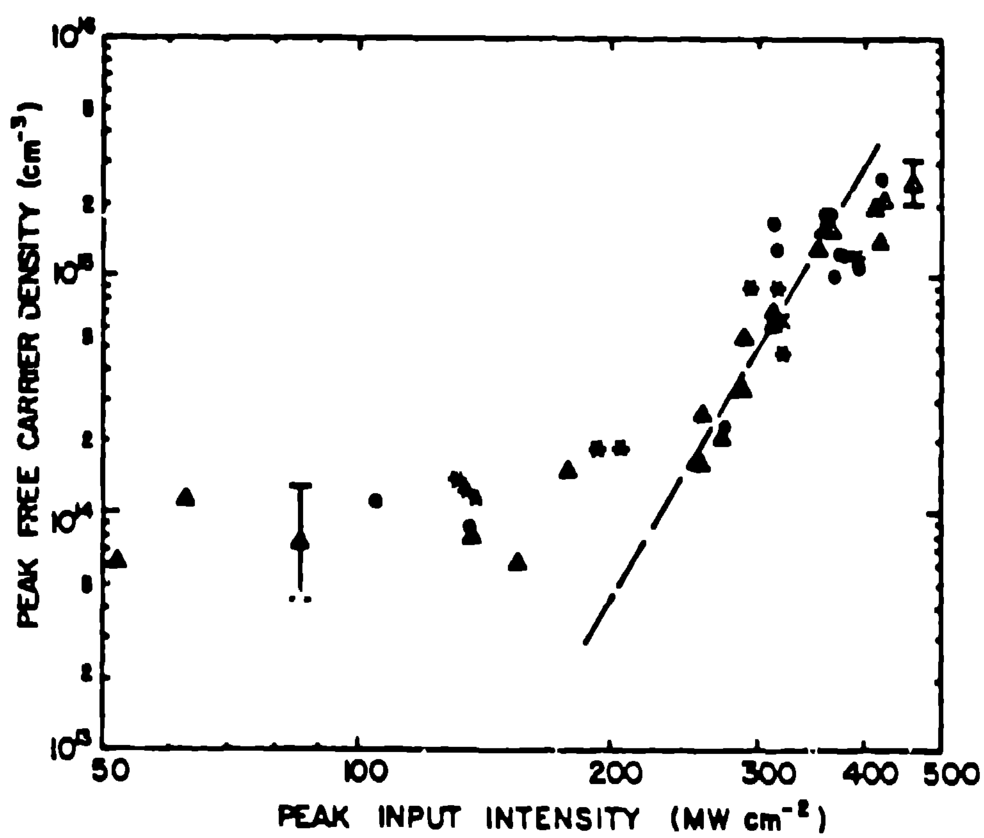

Figure 2